Unwrapping an ancient Egyptian mummy using x-rays

Dr. Stephen W. Hughes
Department of Physics
Queensland University of Technology, Gardens Point Campus,
Brisbane, Queensland 4001, Australia
Phone: +617 3285 3087
Email: sw.hughes@qut.edu.au

Abstract
This article describes a project of unwrappin an ancient Egyptian mummy using x-ray computed tomography (CT). About 600 x-ray CT images were obtained through the mummified body of a female named Tjetmutjengebtiu (or Jeni for short), who was a singer in the great temple of Karnak in Egypt during the 22nd dynasty (c. 945-715 BC). The x-ray CT images reveal details of the remains of body organs, wrappings and jewellery. 3D reconstructions of Jeni's teeth suggest that she was probably only around 20 years old when she died, although the cause of death cannot be ascertained from the CT scans. The CT images were used to build a 3D model of Jeni's head which enabled an artist to paint a picture of what Jeni may have looked like during life. A PowerPoint presentation and movie clips are provided as supplementary material that may be useful for teaching.

Introduction

This article describes work done in the early 1990's to effectively 'unwrap' an ancient Egyptian mummy using x-rays. This project has resulted in a number of publications in research journals [1-6] and also numerous presentations to the public and school groups. Over the years people have suggested to me that the material be packaged as an educational resource, and so this article has been written. A PowerPoint presentation and video clips have been provided as supplementary material as a teaching resource (these are listed in table 1). The project is a good example of technology transfer, where a technology developed in one field, i.e. medicine, is used in another, i.e. archaeology.

Background to the project

At St. Thomas' Hospital, London I developed a computer program for planning the treatment of malignant brain tumours using radioactive iodine-125 seeds [6]. To plan the surgery, a series of x-ray CT scans were acquired through a patient's head and used to generate a 3D model of the patient's head. One night, I heard a report on the radio about work done at Manchester University, UK to physically unwrap a collection of mummies. This led to the idea of using the technology developed for planning brain surgery to electronically 'unwrap' a mummy. The Department of Egyptian Antiquities of the British Museum were contacted

and they were interested in this project as it would be the first time a mummy from the BM had been imaged on a CT scanner.

The staff in the Egyptian department of the BM chose a female mummy called Tjentmutengebtiu, on the basis that the mummy would fit into the aperture of the CT scanner and the mummy was from the 22nd Dynasty (c 945 – 715 BC), which is the period in Egyptian history when the art/science of embalming is considered to have reached its peak. As we shall, see the excellent condition of the mummified body shows that the embalmers of the 22nd Dynasty did do an excellent job.

The mummy's name, Tjentmutengebtiu, is difficult to pronounce and so the mummy has become known as *Jeni* (by taking the second to fourth and penultimate letters of her name). We do not know much about Jeni as a person. Virtually all that we know is obtained from the Egyptian hieroglyph writing on Jeni's coffin. From her coffin, we know her name, the name of her father (Khonsmes) and mother (Mehenmutemhat), and that was a chantress or singer in the great temple of Amun in Karnak. The gilded face and vulture headdress indicate that Jeni had a high rank in society. Jeni was most probably discovered in one of the tombs cut into the rock cliffs near Thebes and arrived at the BM in 1891.

Coincidentally, Jeni left the BM exactly a century later to be scanned at St.Thomas' Hospital (STH) on the south bank of the River Thames in London. She did not have far to go as STH is only about 2.3 km (as the Ibis flies) from the BM. Jeni had been x-rayed before in the 1960s, however on that occasion she never left the museum as a portable x-ray unit taken to the museum from the Royal Marsden Hospital in London. For this project transport of a CT scanner from the hospital to the museum was out of the question and so Jeni had to be brought to the scanner.

X-ray CT scanning

An x-ray CT scanner produces cross sectional images of the body. This is different from a conventional plain X-ray in which, for example, the ribs, lungs, and heart appear superimposed on each other, making it difficult to ascertain the precise depth of an unknown object (e.g. foreign body). On a plain x-ray, an object on the surface of the body may actually be embedded within the body, and the only way of telling whether or not this is so is to take an x-ray from a different direction.

An x-ray CT image is different from a plain x-ray in that it gives a cross-sectional view of the body showing objects in their true relation to each other. For more detail on the operation of an X-ray CT scanner see Michael [7]. It is interesting to note that a mathematical technique known as *Fourier analysis*, used in reconstructing CT images (and incidentally magnetic resonance images) was developed by a scientist on Napoleon's (1769-1821) 1799 expedition to Egypt by the name Jean Baptiste de Fourier (1768-1830). For the record, the other imaging modalities used in medicine are unsuitable for scanning mummies for reasons that we do not have the space to go into here.

Previous work on scanning mummies

Various mummies have been CT scanned throughout the world, for example at universities in Boston and Philadelphia in the USA and Bristol and Manchester [8-9] in the UK. There have been various projects to physically unwrap mummies to see what lies within; perhaps the most notable project being that carried out at the Manchester University Museum in the mid 1970s [9].

There are advantages and disadvantages to either unwrapping or scanning a mummy. For example when a mummy is unwrapped, tissue samples can be taken and analysed, but you end up with a pile of bones, yards of linen and possibly a broken coffin. CT scanning enables the undisturbed internal arrangement of the mummy to be studied and information obtained from inside the bones, which would be difficult to achieve even if a mummy were unwrapped.

Scanning Jeni

During the day, CT scanners are of course used to scan patients and so Jeni was always scanned in the evening when the scanner was no longer being used (although on one occasion we had to wait for a patient to be scanned who had fallen from a London bus). Jeni arrived late for her first scan on the evening of the 10th of December 1991 as the car transporting her broke down at the museum and needed to be repaired. Whilst on the way one of the museum staff said that the radio wouldn't work properly (people were heard to question whether or not the car was a recipient of the mummy's curse!).

Figure 1. Jeni on the scanner couch. (the author is seen on the left). (Image taken from article by Hughes *et al* [5], with kind permission of the APESM).

As Jeni was wheeled into the scanner room you could feel the excitement in the air. The room was packed with people, many of whom had stayed at work late to witness this unusual event. Most of us were not quite sure what to expect. Would there be anything to see? Would the x-rays be able to penetrate the case? Two of us donned surgical gloves and gently lifted Jeni onto the scanner couch (figure 1). Jeni was surprisingly light. With hindsight this is not so surprising when we realise that on average we comprise about 75% water, so Jeni was only about one quarter of her live weight. The body-hugging (anthropoid) case is a light-weight mixture of linen and plaster called *cartonage*, so this wouldn't have added much weight.

Jeni is completely enclosed in an anthropoid coffin, apart from a crack in the head of the case. Just after we placed Jeni had on the couch, I shone a torch into the crack and saw the linen wrapped around her head. Fragments of linen, nearly 3000 years old fell out and lay sprinkled on the couch like bits of burnt paper. A scout x-ray film (figure 2), shows that Jeni's head is lower than the head of the coffin. (Note that a CT scanner can be used in conventional mode to produce an image called a *scout film*, which looks similar to a plain x-ray taken with an ordinary x-ray machine).

When Jeni had been correctly positioned on the couch, everyone was cleared from the scanner room and went into the control room to watch the scanning from behind the protection of a lead impregnated glass window. Live patients are told over the intercom to keep still and to hold their breath if necessary. I am sure that one of the radiographers was about to tell Jeni to stop breathing, but realised just in time that this would be unnecessary! (A video clip is available as supplementary material, showing Jeni on the couch)

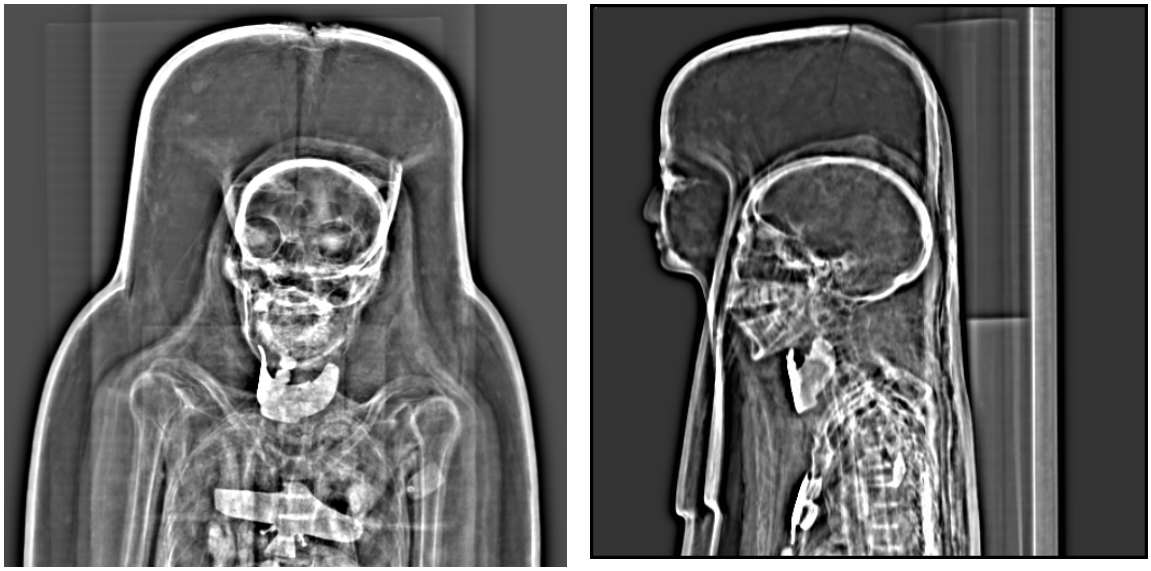

Figure 2. Topographic or scout view of the top of Jeni's mummy case showing that body within. (a) Anterior – posterior (front-back) view and (b) lateral (side) view. Note the crack in the case and the amulets (ritual jewellery) on Jeni's neck and sternum. The lateral x-ray shows that Jeni's mouth was slightly open. (Images taken from article by Hughes et al [5], with kind permission of the APESM).

Jeni was scanned on a Siemens DRH Somaton scanner (Siemens AG, Erlangen, Germany). In total, 115 CT images were acquired of Jeni's head using an image slice thickness of 2 mm and an image size of 512 × 512 pixels. Images were acquired contiguously so that the centre of each image slice was separated by 2 mm. Pixels were 0.5 mm square and 12 bits deep (i.e. 4096 grey levels). The x-ray tube potential was 125 kV and the current 210 mAs. For the rest of the body (i.e. the neck down) x-ray CT images were 4 mm thick separated by 4 mm. About 600 X-ray CT scans were required to scan the whole of Jeni's body.

The first scans showed the thin walls of the case and then a ghostly patch of white appeared as the x-rays cut through the head bandages, a few scans later the top of the skull appeared. The head images acquired on the first night were stored on computer tape[1] and transferred onto a graphics computer in the medical physics department at St. Thomas' Hospital.

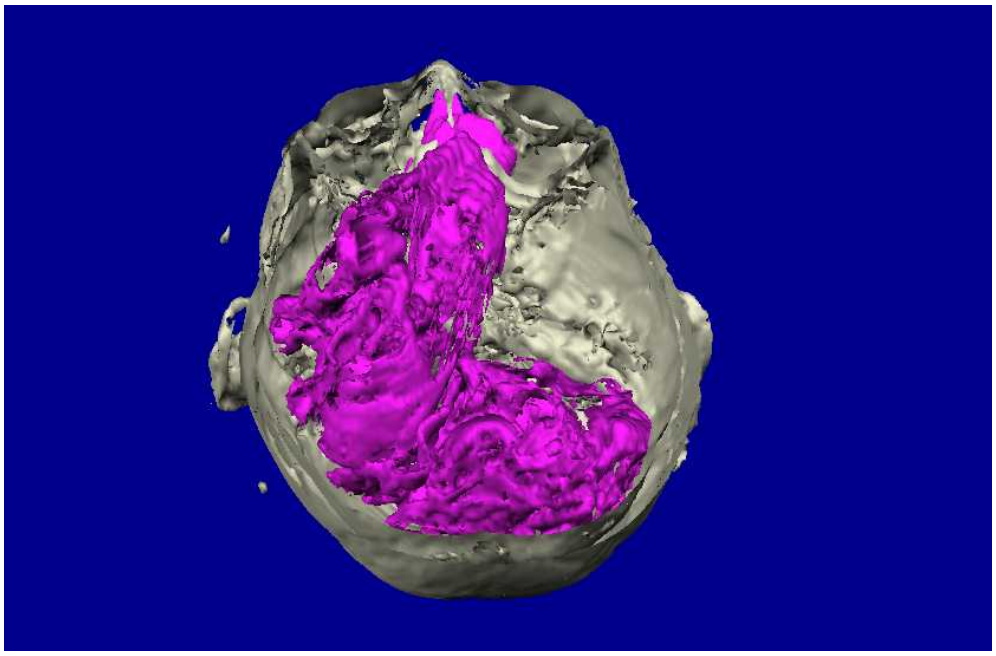

Figure 3. The lower portion of a 3D reconstruction of Jeni's skull showing linen (in false colour) that has been pushed through the nostrils into the cranium to absorb residual fluid after extraction of the brain. (Image taken from article by Baldock *et al* [2], with kind permission of the RSM).

The x-ray CT scans show that the cranium is empty, apart from a few wispy pieces of cloth, indicating that the brain has been removed. Jeni's skull appears to be intact, and so an interesting question is, how did the Egyptian embalmers manage to remove Jeni's brain without obviously damaging her skull? A 3D reconstruction of the lower part of Jeni's skull is able to answer this question and shows that the cranium contains a wad of linen converging on the nostrils (figure 3).

It is known that the embalmers sometimes removed the brain through a hole in the base of the skull called the foramen magnum (literally *big hole*), which is where the spinal cord enters

[1] Remember that this was the 'old' days – there was no internet connection to the scanner or USB sticks!

the cranium. In Jeni's case there is no evidence of decapitation and the fact that the linen appears to converge on the nostrils indicates it must have been pushed in this way. If the linen were pushed in through the foramen magnum, it would be highly unlikely that the linen would converge on the nostrils.

In this case the CT scan confirms that Jeni's brain was removed through her nose. It is known that the embalmers did this by putting a spike up the nose and crunching through the ethmoid bone[2] into the cranial cavity. The aim of embalming was to preserve the body after death and the Egyptians learned by the 18th dynasty that they needed to remove the brain to achieve this. A long hook (see PowerPoint slides), a bit like a bent knitting needle, was used to mash the brain and remove it piecemeal through the nose. Forceps (the medical term for tweezers) were available to assist with pulling out the bits of brain. After the brain was removed, linen was pushed through the nose into the cranium to mop up any residual fluid.

As well as physical preservation of the body, the task of the embalmers was also to preserve the 'look' of the deceased. In this respect, one problem that the embalmers had to overcome was shrinking of the eyes. They overcame this problem by inserting artificial eyes, often made of glass, into the shrunken eye sockets. In some cases small onions were used instead of stones. This was probably because onions cause the eyes to water and therefore the Egyptian assumed that there was some kind of 'sympathetic' connection between onions and the eyes. Jeni's natural eyes have been replaced by artificial glass eyes in two sections, with the front section (the 'pupil') being more dense that the rear section (corresponding to the 'white' of the eye).

The lateral x-ray of Jeni's upper body body (figure 2(b)) shows that her mouth is slightly open. This is due to linen placed in her mouth. I performed some 'surgery' on a 3D reconstruction of Jeni's skull to close her jaw (figure 8 (top left panel)).

Jeni was transported to STH on five separate occasions[3]. On the fifth and final occasion, Jeni's teeth were scanned in high resolution. Image slices were 1 mm thick separated by 1 mm[4], with a high magnification factor so that the teeth filled most of the field of view. These images were used to generate a detailed reconstruction of Jeni's teeth (figure 4). These images of the teeth exemplify the power of CT as the x-rays have penetrated all the way through the outer case, through the many layers of linen, through the dried and hardened skin and eventually passing through the teeth. (On one occasion I was showing the 3D images of the teeth to a forensic dentist when a maxillo facial surgeon walked in and assumed that the teeth on the screen were real teeth! This convinced me of the power of CT).

[2] Which has a similar consistency to Crunchy bar chocolate

[3] On a modern helical scanner it would be possible to scan the entire body in just a few minutes

[4] A live patient would never be scanned in this was due to the very high radiation dose that would be received – but in this case radiation dose was not a problem

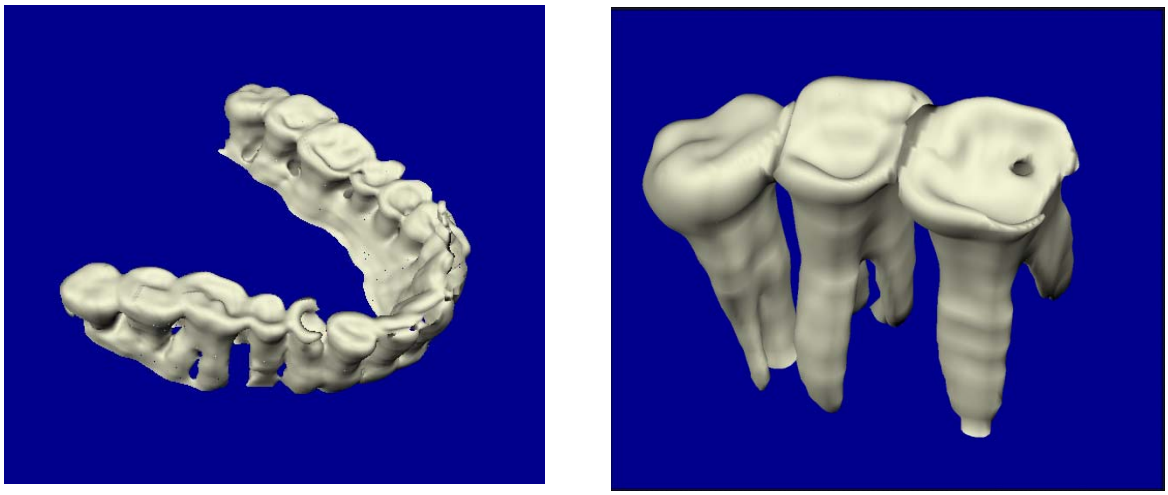

Figure 4 (a). 3D reconstruction of Jeni's upper teeth showing that they are in fairly good condition consistent with a young Egyptian. A 3D reconstruction of Jeni's upper left molars (seen at the top of (a)) is shown on the right (b). ((b) taken from article by Baldock et al [2], with kind permission of the RSM).

On a computer, the teeth can be extracted from the surrounding image and displayed in isolation, as shown in figure 4. The fact that Jeni's teeth are in very good condition suggests she was young when she died. By middle age, most Egyptians' teeth were in very bad condition, for example they would have lost several teeth, suffered from abscesses and the enamel (the hard outer coating) on the remaining teeth would be worn down to the pulp. Examples of such teeth can be seen behind the scenes in the Department of Egyptian Antiquities of the BM (see PowerPoint slides).

The 3D images of some of Jeni's molars (the back teeth) were examined in more detail (figure 4(b)). The top, biting surface, of the first second and third molars show a clear difference in wear. The first molar is more worn than the second, which in turn is more worn than the third (wisdom tooth). The first molar generally erupts at age six years, the second molar at 12 and the third around 17 (if at all). The open shape of the roots of Jeni's wisdom teeth suggests that she was only 19-23 when she died. An estimate of the amount of bone mineral in the lumbar vertebrae of her spine is also consistent with a young age at the time of death [4].

The absence of any obvious physical injuries seems to rule out violent death (being attacked by a crocodile for example) so the cause of Jeni's death still remains a mystery 2700 years later. However, the original x-ray report does refer to three of Jeni's ribs being fractured although these cannot be seen on the CT scans. Jeni also has a fracture of her right pelvic bone. (Plain x-rays are much better at picking up fine cracks than CT). It does not automatically follow that the fractures in Jeni's ribs were the cause of her death since the fractures could have occurred post-mortem. Apparently the embalmers could be a bit rough and used to stack bodies when they had a backlog, as might happen, for example, during a plague.

However, a blow to the body could have caused the fractures on the right side of Jeni's body. It is possible that Jeni sustained these injuries by falling out of a building or being hit by a chariot. If Jeni was involved in an accident which resulted in a blow to her head she could have received a subarachnoid haemorrhage (bleeding on the surface of the brain) which could have been serious enough to kill her. Out of interest, the Egyptian physicians were able to treat blood clots on the brain (from bleeding) by drilling a hole through the skull to relieve pressure (a process known as *trepanning*). There is no evidence of this being done in Jeni's case, and the cause of Jeni's death being head injury is only supposition anyway.

Jeni had the most expensive embalming technique performed on her, which involved the removal of the brain in the manner described above. To remove the lungs and viscera, a slit was made in the left flank with a flint knife and the lungs, liver, stomach and intestines removed and dried separately from the rest of the body. Figure 5 shows an X-ray CT scan through the embalming slit. The dark rays emanating from the embalming plate indicates that it is made of metal.

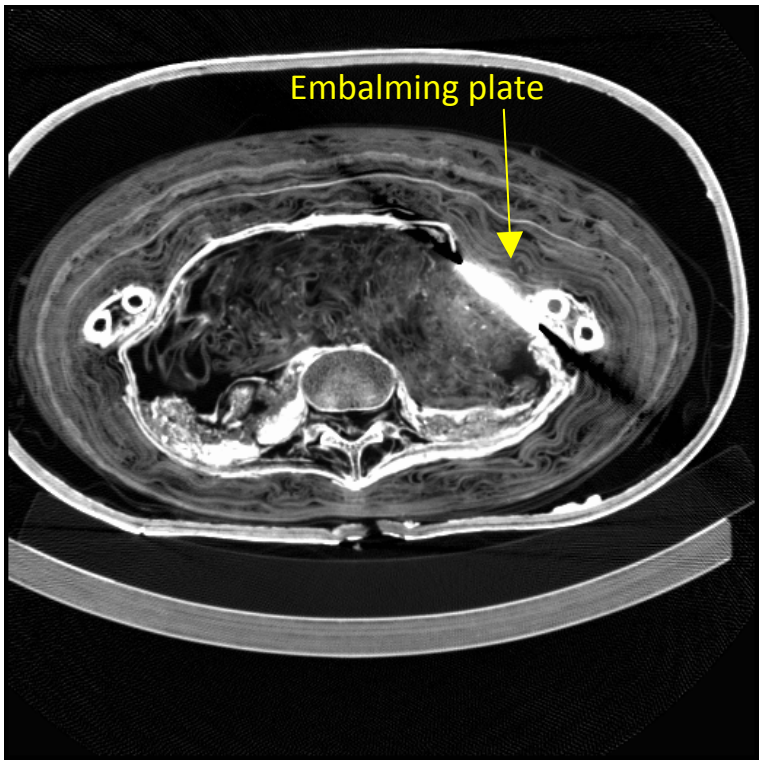

Figure 5. X-ray CT image through the embalming plate. The rays are artefacts caused by the presence of metal in the plate. (Image taken from article by Hughes et al [5], with kind permission of the APESM).

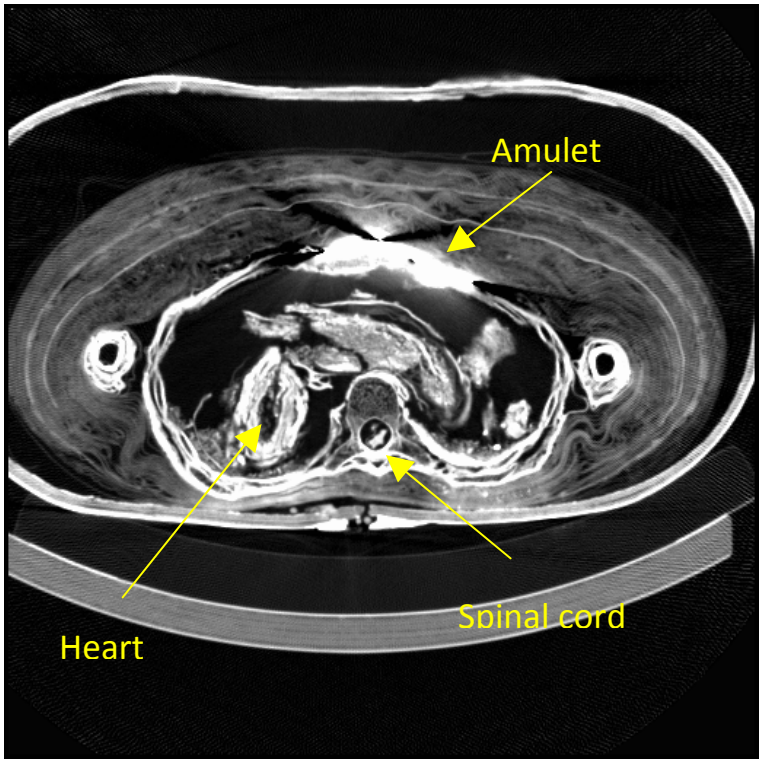

Figure 6. X-ray CT image through the organ packs in the thorax. The remains of the heart and spinal cord can be seen. The object on the sternum is some kind of amulet (probably of a hawk). The dark rays are due to interference caused by metal in the amulet. (Image taken from article by Baldock *et al* [2], with kind permission of the RSM).

When Jeni was embalmed, her heart and kidneys were left in place; the remains can be seen (figure 6). After removal of the viscera, the thorax and abdomen were packed with natron, and the body covered with natron for 40 days. After this time the body was completely dry. (Drying is a very good way of preserving the body - as it is for other things such as dried fruit). Natron is a naturally occurring mixture of sodium salts (bicarbonate, sulphate and chloride); basically table salt with extras, which the Egyptians obtained from a place called Wadi Natron, about 50 km north west of Cairo.

Over the next 30 days (making a total mummification period of 70 days) various spices, unguents and resins were applied inside and outside the body. The dried liver, stomach, lungs and intestines were wrapped separately and placed back inside the body, but in the thorax rather than the abdomen, which was filled with natural fibre. The incision in the flank was closed using wax or stitches, and a plate, made of either wax, metal or gilded wood, inscribed with a protective eye (the *udjat*), placed over the incision.

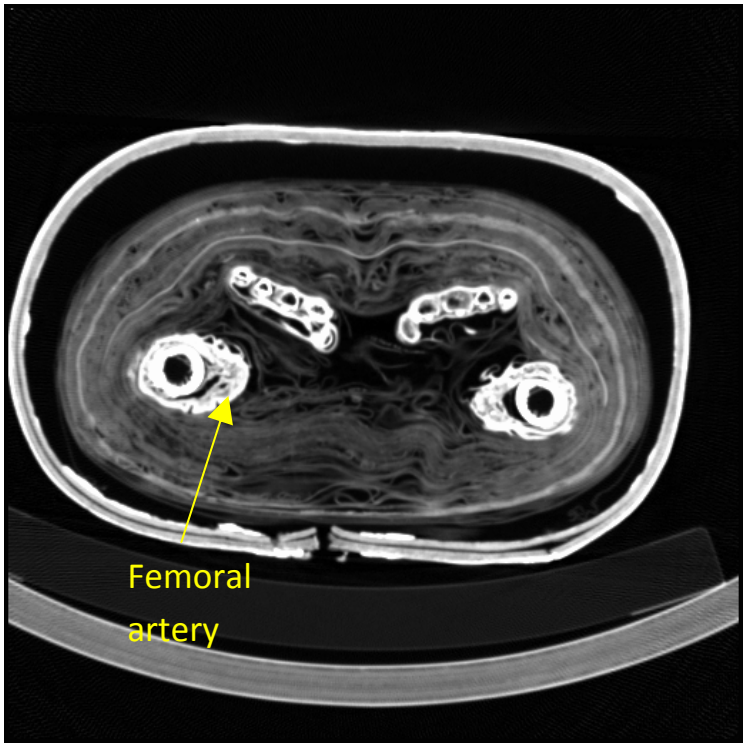

Figure 7. A cross sectional X-ray image through Jeni's hands and femur. Note that Jeni is so well preserved that even the femoral artery is still visible on the left.

Jeni is so well preserved that parts of her spinal cord can still be seen, and even arteries in her legs (figure 7). Arteries have muscular walls that remain open at death, unlike veins which collapse like fire hoses when the blood flow ceases. A 3D reconstruction of Jeni's skull has enabled an artist to paint an impression of what Jeni may have looked like during life (figure 8).

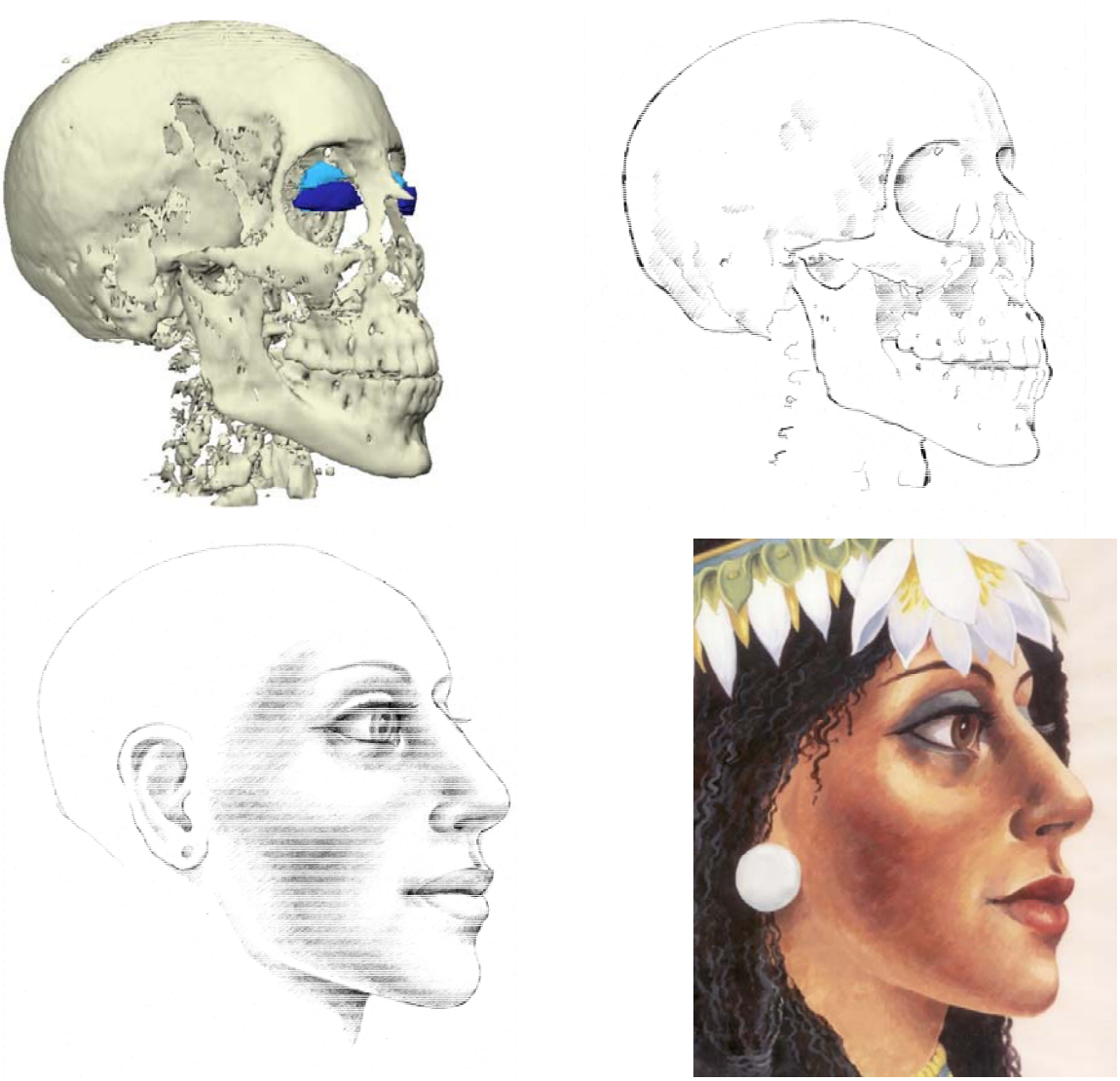

Figure 8. Four views showing how an artist (Maureen Hart of Horley, Sussex, UK) produced a picture of what Jeni may have looked like during life. The top left panel shows a lateral oblique view of a 3D surface rendering of Jeni's skull. The top right panel shows an outline of the skull as transferred onto tracing paper. The bottom left panel shows a fuller outline of Jeni's face based on the skull outline. The bottom right panel shows an impression of what Jeni may have looked like when she was alive. The dimensions of Jeni's skull were also entered into a computer program that was able to identify her as a Middle Eastern female [4].

Table 1. Resources available for teaching. (All mov files are Quicktime movies). The small movie files are available from the IoP website and the larger files (and therefore of higher quality) are available from the Queensland University of Technology eprints site (http://eprints.qut.edu.au/31522).

Filename	File size (MB)		Description
	Large	Small	
Jeni.pptx	16.7	-	PowerPoint slides describing the project
Jeni slide notes.pdf	0.032	-	Notes for PowerPoint slides
Jeni CT fly through.mov	94.5	7.7	A movie of all the x-ray CT scans from Jeni's head to her feet
Jeni rotating skull.mov	7.3	2	360º degree rotation of a 3D reconstruction of Jeni's head
Jeni head skin to bone.mov	11.6	0.7	A movie showing the change in the x-ray level used to generate a surface rendering of Jeni's face. The mummified skin recedes down to the bone
Jeni on CT couch.mov	39.6	5.9	A movie showing Jeni being placed on the CT couch

Acknowledgements

The author would like to acknowledge the help and support of people who have assisted with the project over the years: Clive Baldock, Mark Barry, Reg Davis, Andrew Harrison, Ajit Sofat, Jeffrey Spencer, John Taylor, Keith Tonge, David Whittaker, Richard Wright. Thanks also to Mark Young for suggesting that the material be packaged as an educational resource.

References

1. Baldock C, Hughes S W, Davis R 1995 3-D reconstruction of ancient Egyptian mummies using CT, *J. Anc. Middle East Soc.* **3** 5-15

2. Baldock C, Hughes S W, Whittaker D K, Taylor J, Davis R, Spencer A J, Tonge K and Sofat A 1994 3D Reconstruction of an ancient Egyptian mummy using x-ray computer tomography *J. R. Soc. Med.* **87** 806-808

3. Hughes S W, Sofat A, Baldock C 1993 CT imaging of an Egyptian Mummy, *Br. J. Non-Destr. Test.* **35** 369-374

4. Hughes S W, 1996 3D reconstruction of an ancient Egyptian mummy *Paper of the British Museum, Occasional paper* no. 114 pp 211-225

5. Hughes SW**,** Wright R, Barry M 2005 Virtual reconstruction and morphological analysis of the cranium of an ancient Egyptian mummy *Australas. Phys. Sci. Eng. Med.* **28** 122-127.

6. Hughes S W, Sofat A, Kitchen N D, Brown A, Beaney R P, Timothy A R, Saunders J E, Thomas D G T 1995 Computer planning of stereotactic iodine-125 seed brachytherapy for recurrent malignant gliomas, *Br. J. of Radiol.* **68** 175-181

7. Michael G 2001 X-ray computed tomography *Phys. Educ.* **36** 442-451

8. Cockburn, A. *et al* 1975 Autopsy of an ancient Egyptian mummy *Science* **187** 1155-60

9. David A R and Tapp E (ed) 1992 *The Mummy's Tale*, (London: Michael O'Mara Books)